A Voided Slab and Conventional Flat Slab; A Comparative Study

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Abstract

The Bubble Deck slab is a newly designed bi-axial concrete floor slab system. High density polythene (HDPE) hollow spheres are placed in the center of slab by replacing the ineffective concrete to decrease its dead weight so increase the efficiency of floor. This abstract deal with work carried out to compare the bubble deck voided slab system and conventional flat slab system by finite element analysis using SAP 2000 as well as manual calculation by Direct design method using IS456:2000 to study the behavior of bending moments, shear force, deflections and reactions due to change in span for various load conditions. The present study is carried out to study the seismic behavior of structure due to reduction in dead weight of structure by modelling and analysis of G+12 storey structure for 6mx 7m , 7m x 8m , 8mx 9m grid systems.
Keywords: Bubble Deck Voided Slab, SAP2000, Shear Force, Bending Moment

I. INTRODUCTION

The flat plate floor systems are commonly used in multi-storey buildings, because flat plate floor system present advantages from technical and functional point of view. The self-weight of slab can reduce by replacing the middle height of the cross section of slab with void former. Actually, the concept of removing non-working concrete from slab cross section is quite old. The voided slab used in construction field more than 50 years. By introducing void former into the slab, self-weight of the slab can be reduce and this lead to reduction in overall cost of the slab. The overall weight of slab is decreasing as much as 35% compared to solid slab of same capacity. The main idea behind voided flat plate slab is to removing the unused concrete from the middle of the slab. The spherical balls, which are inserted in the middle of the flat plate slabs, are manufactured from recycled plastic, which do not react chemically with concrete or steel.

II. LITERATURE REVIEW

Reshma Mathew and Binu.P (2006**)** studied the punching shear behavior of bubble deck slab compared to solid slab. The punching shear capacity of bubble deck slab is small in comparison with solid slab. Hence, the GFRP strips with various orientations are used as a strengthening system for bubble deck slab. Finite element analysis was carried out using ANSYS software. Strengthened slabs have higher punching capacity compared with control bubble deck slab. There is increment in load carrying capacity up to 20% due to strengthened bubble deck slab. By introducing HDPE balls of 180 mm diameter in to a flat slab of thickness 230mm can save the weight up to 23.62% around one ball.

M.Surendar and M.Ranjitham (2016) studied the analysis of bubble deck slab numerically as well as experimentally. For numerical study, the bubble deck slab and conventional slab is analyzed by using ANSYS software with appropriate support conditions and providing uniformly distributed loading. Also, for experimental investigation the test specimens were designed for two types of slabs, one for conventional one way RC slab and other were for one way bubble deck slab. The stress and deformation results were evaluated and compared the bubble deck slab with conventional slab were observed using finite element analysis. By numerical and experimental studies it is shows that the bubble deck slab can withstand 80% of stress when compared with conventional slab. Slight variation occurs in the deformation when compared with conventional slab. At last the comparison has been made for Bubble Deck Slab with the Conventional slab over its self-weight. From the evaluation of these results, Bubble Deck Slab gives better performance than that of the conventional slab.

P. Prabhu Teja et al (2012) discussed the various properties of Bubble deck slab based on the various studies done abroad. Moment, deflection and stress distributions are verified using Finite Element Method (FEM) in SAP2000. The finite element models of the office slabs created for this study in SAP2000 verify the prior analysis and experiments. It gives the bending stresses in the bubble deck slab are found to be 6.43% lesser than of a solid slab. Also, deflection of bubble deck is 5.88% more than the solid slab as the stiffness is reduced due to hollow portion. Further, the shear resistance of bubble deck slab is 0.6 times the shear resistance of the solid slab of same thickness. However required resistance can be achieved by providing vertical reinforcement.

Saifee Bhagat and Dr. K. B. Parikh (2014) studied the parameters of voided slab in terms of moment of inertia, shear capacity, stiffness reduction factor, weight reduction factor and compared with the flat plate slab. The voided flat plate slab and solid flat plate slab are considered with interior span ranging from 6m x 6m to 14m x 14m having thickness from 280mm to 600mm having spherical balls into the slabs from 180mm to 450mm. Self-weight reduction, stiffness modification factor and solid area for punching shear is derived for different cases of voided flat plate slab. From the results, it may be concluded that the reduction of stiffness due to spherical balls are near about 10% to 20%. By introducing spherical voids into flat plate slabs, the self- weight of the slab can be reduced up to 32%. From the results of punching shear calculation, it may be concluded that, the calculated perimeter of solid portion around the column is adequate to take applied shear stress as Ved < Vrd (max).

III. PARAMETERS OF VOIDED SLAB

A. *Stiffness modification factor and Weight Reduction*

Ordinary the second moment of inertia is a key variable when performing structural analysis of slab. The untracked moment of inertia is dependent on the thickness and width of the flat plate slab and the contribution made by steel can be ignored since steel is not taking part prior to cracking. In addition, the values in Cobiax Technology Handbook are taken by calculating second moment of inertia in State-1 (uncracked) and in State-2 (cracked). The results have revealed that the stiffness reduction factor in state-1 is the determining factor. The stiffness reduction factor can be derived from the calculation of second moment of inertia of voided slab and solid slab. With the help of this reduction factor and taking into account the reduced self-weight of voided slab deflection of voided slab can be calculated.

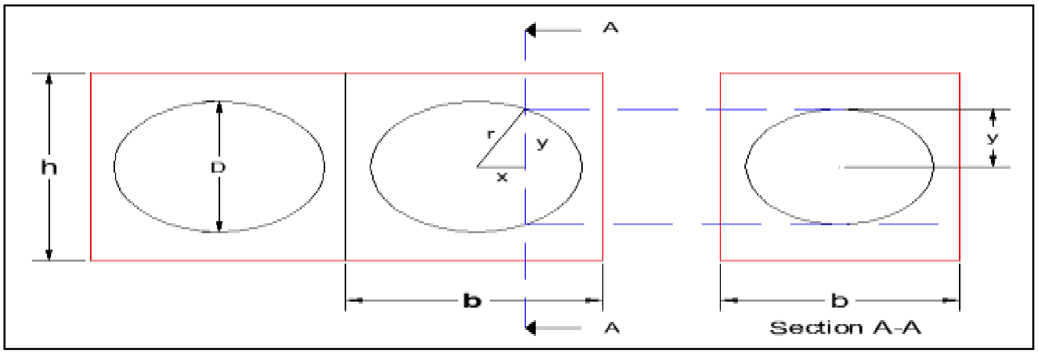

Fig. 1: Section of Voided Slab

To find out weight reduction of voided slab, first find out the volume of solid slab and volume of circle.
Volume of solid slab is
$V_s = b \times h \times h$ and $V_c = 4\pi r^3/3$
Where,
b= Width of solid section surrounding a single sphere.
h=Total thickness of the slab
r = radius of circle
The percentage weight reduction of voided slab is calculated as
% Weight reduction = vol. of Circle / vol. of Solid section

Table - 1
Calculation for weight reduction

% of Weight Saving						
Grid	*Slab Thickness (h) mm*	*Ball Diameter (D) mm*	*Minimum axis spacing (b) mm*	*Volume of Solid Section (Vs) mm³*	*Volume of Circle (Vc) mm³*	*% Weight Saving*
(6x7)	*250*	*180*	*200*	*10×10^6*	*3.05×10^6*	*30.53*
(7x8)	*280*	*180*	*200*	*11.2×10^6*	*3.05×10^6*	*27.25*
(8x9)	*310*	*225*	*250*	*19.4×10^6*	*5.962×10^6*	*30.77*

To find out stiffness multiplication factor first find out the second moment of inertia of solid slab without void former. And this can be calculated with:
$I_s = bh^3/12$
Where,
b= Width of solid section surrounding a single sphere.
h=Total thickness of the slab
Second moment of inertia of circle can find by
$I_c = \pi y^4/4$
To derive the stiffness multiplication factor, Ic can be subtracted from Is and the answer can then be divided by Is.

Table - 2
Calculation of stiffness multiplication factor

Grid	*Slab Thickness (h) mm*	*M. I. of Solid Section (Is) mm^4*	*M. I. of Circle (Ic) mm^4*	*M. I. of Voided Section (Iv) mm^4*	*Stiffness multiplication Factor*
(6x7)	*250*	*260.41×10^6*	*51.52×10^6*	*208.89×10^6*	*0.802*
(7x 8)	*280*	*365.86×10^6*	*51.52×10^6*	*314.34×10^6*	*0.859*
(8x 9)	*310*	*620.65×10^6*	*125.78×10^6*	*494.87×10^6*	*0.8*

B. Bending Strength

The ratio of the moment resisted by the void region to the total moment resisted by the whole cross section (Mvoid / Mu) is denoted by the variable µms. When the value of µms is less than 0.2, the moment stress are allowed to redistribute within the section of the slab and the voided slab can be designed by using conventional design principles. The ratio µms is calculated as follows:

$\mu ms = Mu\ 1.96D/ (fck \times h^3) \leq 0.20$

Where,

D = Void diameter

Mu = Design moment on the slab, which

h = Overall depth of the slab can be derived from structural analysis

$Mu = wL^2/8$

w = total factored load

L = Length of slab in larger direction

To find the design moment, following parameters are considered:

- Applied loads
  1) Self weight
  2) Floor finish = 1.0 KN/m^2
  3) Wall Load = 2.0 KN/m^2
  4) Live Load = 3.0 KN/m^2
- Grade of Concrete = M25
- Grade of Steel = Fe 415

Table - 3
Test result of µms

Bending Strength							
Grid	*Self Weight KN/m^2*	*Floor Finish KN/m^2*	*Wall Load KN/m^2*	*Live Load KN/m^2*	*Total Factored Load KN/m^2*	*Design Moment (Mu) KN.m/m*	*µms*
(6x7)	*4.375*	*1.0*	*2.0*	*3.0*	*15.563*	*95.32*	*0.086*
(7x8)	*5.11*	*1.0*	*2.0*	*3.0*	*16.665*	*133.32*	*0.0857*
(8x9)	*5.425*	*1.0*	*2.0*	*3.0*	*17.138*	*173.52*	*0.1*

C. Punching Shear Strength

The shear force must be calculated from the structural analysis using service load. The areas with high punching shear, such as areas around columns or with high concentrated loads; the solid slab is designed instead of voided slab. The suggestion is often made to leave out the void former around columns to make that portion of voided slab as solid. The perimeter of the solid portion should be calculated from the face of column without shear reinforcement. Punching shear for voided slab should be limited by the following equations:

$V_{ED} < V_{RD(max)}$

$V_{ED} = V_{max} /(u_{col} \times d_{om})$

$V_{RD(max)} = 0.5\ V \times Fcd$

Where,

u_{col} = perimeter of the column

d_{om} =mean effective depth of slab

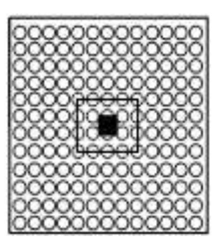

Fig. 3: Punching Shear for Voided Slab

Fig 3.shows that the spherical balls are omitted around the column and make it solid. The spherical balls, which are removed from the voided flat plate slab, are presented by dotted ball in fig 4. The perimeter of the solid portion is calculated for the span 6m x 7 m, 7m x 8m, 8m x 9m having thickness of the voided flat plate slab 250mm, 280mm and 310mm respectively.

Table - 4
Punching Shear Strength

Grid	*Total Factored Load KN/m²*	*Shear Force (Vu) KN*	*Perimeter for punching mm*	*Nominal Shear Strength V_{ED} N/mm²*	*Shear Strength of Concrete $V_{RD(max)}$ N/mm²*
(6x7)	*15.563*	*653.625*	*3200*	*0.972*	*5.55*
(7x8)	*16.665*	*933.24*	*3200*	*1.215*	*5.55*
(8x9)	*17.138*	*1233.9*	*3200*	*1.428*	*5.55*

IV. ANALYSIS OF VOIDED SLAB AND SOLID SLAB USING SAP2000

A. *Deflection of slab*

The analysis for deflection is carried for voided flat slab and solid flat slab in SAP 2000 for grid 6m x 7m, 7m x 8m and 8m x 9m having thickness 250mm, 280mm and 310mm respectively. To obtain the results the modified value of Self-weight and Stiffness multiplication factor is applied for voided slabs. The results have shown that for all the cases, the deflection is almost same for voided and solid flat slabs under same loading condition at the same point and results are match with numerical calculation.

Table - 5
Result of Deflection for Voided and Solid flat slab

Span Grid (m)	*Slab Thickness (mm)*	*Ball Diameter (mm)*	*Deflection (mm)*	
			Voided Slab	*Solid Slab*
6 x 7	*250*	*180*	*3.5*	*3.7*
7 x 8	*280*	*180*	*4.5*	*4.8*
8 x 9	*310*	*225*	*5.7*	*6.1*

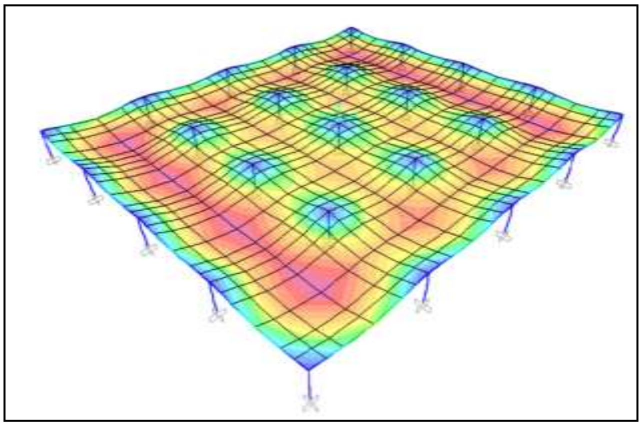

Fig. 4: Deflection of Voided Flat Slab

B. *Maximum Bending moment*

The results for moments are also carried out same as deflection for all the cases considering only gravity loading. Here the results of moment show at the point where the maximum positive moments are occurred. From the modelling of the slabs, it revealed that for both the system voided flat plate slab and solid flat plate slab, the location of point is same where the maximum positive moment occur. The SAP 2000 results show that the maximum moments in the voided flat plat slabs are 7 to 10 % less than that of the solid concrete slab under the same loading conditions. This is a consequence of the decreased dead load from the hollow spheres in place of concrete.

Table - 6
Result of Moment for Voided and Solid flat slab

Span Grid (m)	*Slab Thickness (mm)*	*Ball Diameter (mm)*	*Moment (KN.m/m)*	
			Voided Slab	*Solid Slab*
6 x 7	*250*	*180*	*209.22*	*210.22*
7 x 8	*280*	*180*	*263.5*	*293.66*
8 x 9	*310*	*225*	*348.64*	*395.7*

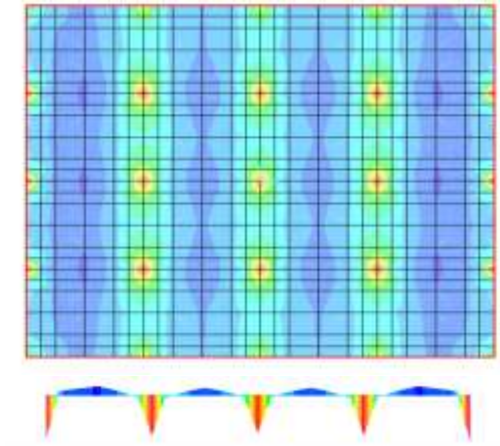

Fig. 5: Moment of Voided Flat Slab

C. *Reaction*

The main purpose of to carry out results for reaction is to confirm that the methodology that was adopted to perform the study of voided and solid flat slab is acceptable or not. It means that applied stiffness multiplication factor and modified self-weight of the voided slabs are correct or not.

Table - 7
Result of Reaction for Voided and Solid flat slab

Span Grid (m)	*Slab Thickness (mm)*	*Ball Diameter (mm)*	*Reaction (KN)*	
			Voided Slab	*Voided Slab*
6 x 7	*250*	*180*	*730.53*	*730.53*
7 x 8	*280*	*180*	*1020.11*	*1020.11*
8 x 9	*310*	*225*	*1314.98*	*1314.98*

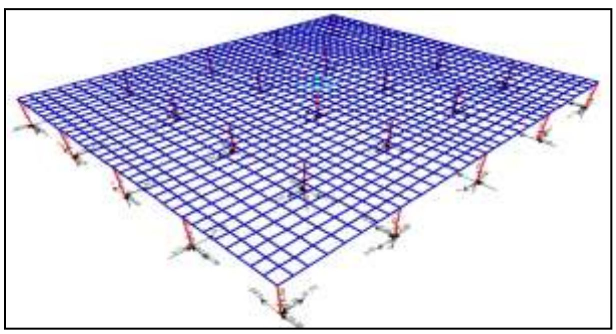

Fig. 6: Reaction of Voided Flat Slab

V. ANALYSIS OF VOIDED SLAB AND SOLID SLAB USING MANUAL CALCULATION

The analysis of voided flat slab and solid flat slab is carried out by manual calculation using Direct design method as per IS456:2000 for grid 6m x 7m, 7m x 8m and 8m x 9m having thickness 250mm, 280mm and 310mm respectively. To obtain the results the modified value of Self-weight and Stiffness multiplication factor are used as per Bubble deck guide.

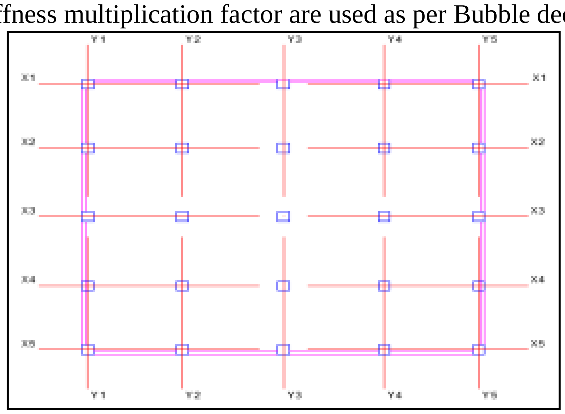

Fig. 7: Typical Floor Plan

Table - 8
Result of analysis for Voided and Solid flat slab

Results of Voided and Solid slab (Direct Design Method)						
	Solid	Voided	Solid	Voided	Solid	Voided
Slab Thickness (mm)	250		280		310	
Deflection (mm)	5.9	6.2	7.57	7.53	9.45	9.81
Max B.M KN.m	312.53	272.78	525.01	455.86	822.68	695.73
Reactions KN	759.24	643.67	1074.22	918.52	1460.72	1214.28

VI. ANALYSIS OF G+12 STRUCTURE USING VOIDED SLAB AND SOLID SLAB BY SAP2000

The analysis of G+12 storey structure using voided slab and solid flat slab for grid 6m x 7m, 7m x 8m and 8m x 9m having thickness 250mm, 280mm and 310mm respectively is carried out to study the seismic effect on whole structure due to reduced concrete weight.

Table - 9
Base Shear Comparison For G+12 Structure

Base Shear Comparison for G+12 structure						
	Solid	Voided	Solid	Voided	Solid	Voided
Grid Span	7m x 6m		8m x 7m		9m x8m	
Slab thk	250mm		280mm		310mm	
Zone Factor(z)	0.16		0.16		0.16	
Importance Factor (I)	1		1		1	
Response factor(R)	3		3		3	
Height (H) in m	39		39		39	
Time Period (T) in sec	1.17		1.17		1.17	
Sa/g	0.854		0.854		0.854	
Horizontal seismic Coefficient (Ah)	0.0227		0.0227		0.0227	
Seismic Weight (W) in KN	205013.7	176956	327691.3	288301.3	433106.8	371326.7
Base Shear in KN	4670.81	4031.57	7465.76	6568.34	9867.43	8459.9
Reduction in Base Shear	13.68%		12.02%		14.26%	

VII. CONCLUSION

1) The methodology adopted for the modelling of the voided flat plate slab, that is by substitution of stiffness reduction factor and modified self-weight of the voided flat slab is acceptable because, the results of reaction is same for reinforced concrete voided and solid flat plate slab systems.
2) For all the cases of the voided flat slab, the results for deflection is almost same as compared to that of solid flat slabs under same loading and at the same point. Therefore, by applying the stiffness reduction factor, we can obtain the deflection of the voided flat slab same as solid flat slab.
3) Same as deflection, results of moment is also observed for various cases of voided and solid flat plat slabs. From the results, it may conclude that, due to reduced self-weight of the voided flat plate slab, the moment of the slabs is reduced from 7 to 10 % of the solid flat slab at the same point under same loading condition.
4) It is concluded that using voided flat slab system the base shear of structure is reduced by 12 to 14 % due to reduced concrete weight.

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